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To Mr. M.A. Machacek
Manager - Engineering
Darlington GS
Design and Construction Branch

Attn: Mr. M.S. Ho

INSTRUMENTATION REPORT - DARLINGTON GS TURBO-GENERATOR UNITS 1 and 2 STABILITY INSTRUMENTATION REPORT

D.S. Fraser

This report describes the instrumentation and installation technique used in the turbo-generator settlement monitoring program at Darlington GS. Similar installations have been successfully completed at Bruce GS B, Units 5 to 8. The datum readings for Units 1 and 2 are presented in the Appendix. An addendum will be prepared as the remaining readings are obtained.

INTRODUCTION

Four single shaft turbo-generators of 850 MW are being installed at Darlington GS. Due to the massive size and complexity of the turbo-generator foundations, it was considered that information on their stability performance should be obtained.

A request was made by Design and Development on June 22, 1983, for the Civil Research Department to design, fabricate and supervise the installation of the following instrumentation for the purpose of measuring turbo-generator foundation stability:

1. 12 settlement stations at elevation 101.0 m on turbo-generator support columns

2. 12 combination stations on the turbine table (elevation 115.0 m) for horizontal alignment, vertical settlement and dynamic velocity measurements.

3. 4 plumb lines from the underside of turbine table (elevation 110.0 m) to ground floor (elevation 101.0 m)

job	file	date	report no.
43-541-450	843.12	August 12, 1987	87-175-K

4. 12 sets of gap measuring stations at table spring supports (elevation 110.0 m)

5. 1 invar extensometer from elevation 101.0 m to 115.0 m

6. 1 deep rock benchmark inside the powerhouse adjacent to the foundation of Unit 2

7. 30 thermocouples in Unit 2 concrete turbine table

All instrumentation is to be read before the turbo-generator is erected, after erection, and with the turbo-generator operating at full load.

This monitoring program is to be carried out on all four units with fewer instruments installed in Units 1, 3 and 4. This report deals specifically with that carried out on Units 1 and 2.

MEASURING STATIONS

The instrumentation for Units 1 to 4 at Darlington GS was selected on the basis of past experience gained in making similar measurements at the Bruce NGS "B" Units 5 to 8.

The following instrumentation was worked out in detail and the installation on Unit 2 was successfully completed at the beginning of 1986. The installation on Unit 1 is now also complete. The installation on Units 1 and 2 are identical with the exception that Unit 1 does not have a deep rock anchored benchmark, an invar rod installation, or temperature monitoring thermocouples.

LOWER SETTLEMENT STATIONS

Twelve locations were selected on the T-G support columns (six on each side of the structure) at elevation 101.0 m.

(a) The purpose of these stations is to monitor the total differential vertical movement at the base of the pier columns of the structure. These measuring stations each consist of one 19 mm x 50 mm long hexagonal stainless steel socket permanently grouted into the concrete on the outside face of each pier column at elevation 101.0 m as shown in Figure 1, detail 'C'. A special type of cement (commercially available under the trade name of INPAKT cement, C.C. Chemicals Ltd) was used. This cement expands to fill the cavity and grip the socket firmly within a hour of application. Stainless steel reference pins were made up and permanently screwed into each socket using LOCTITE THREADLOCKER 242. The pins have a movable head piece with a ball bearing as the survey reference point which is oriented vertically and then locked in place with the same threadlocker. Darlington Construction fabricated protective covers for these stations which are removed each time a reading is taken and then replaced. Each station is identified by a number (C-1, C-1A, C-2, C-2A, etc) which will be painted on the concrete below the station.

(b) The elevation of each reference station is obtained by the optical method using a Wild-N3 precise level reading to the tenths and hundredths of a centimeter and a 1 meter invar stadia rod graduated in centimeters. Readings are made to 0.1 mm (0.004 in). To take a measurement, the 1.0 m invar rod is placed on the top of the ball bearing of the reference pin using the flat bottomed foot of the rod. Using the Wild-N3, and standard procedures for precision leveling, measurements on the complete traverse of the 12 reference stations are made. An accuracy of +/- 0.015 mm for any station relative to the datum station under favourable working conditions is achievable. The initial datum readings are tabulated in Table I. All elevations are given relative to column station C-1A.

UPPER SETTLEMENT STATIONS

Twelve multi-purpose stations are located on top of the turbo-generator support table at elevation 115.0 m (operating floor). The location of these stations is shown in Figure 2.

(a) The purpose of these stations is to measure differential movements of the machine floor in both the vertical and horizontal directions as well as provide a reference point for monitoring vibration levels of the structure. A traverse of six specially designed reference stations was installed at the centreline of each bearing of the machine in a straight line on each side of the table. Each station is provided with a protective cover. See Figure 1, detail 'B', for an illustration of these stations.

(b) The elevation of each of the twelve reference stations is obtained to an accuracy of 0.1 mm (0.004 in). The 2.0 meter invar levelling rod, with a flat seat is held on the rounded top of the reference station. Using the Wild-N3 precise level and standard procedures for precision levelling, measurements on the complete traverse of 12 reference stations are made. An accuracy of +/- 0.15 mm for any station relative to the datum station, under favourable working conditions, is achievable. Any vibration or heat produced when the unit is running decreases this accuracy. The initial datum readings are tabulated in Table II. These elevation readings are given relative to table station T-1A.

UPPER ALIGNMENT STATIONS

The same twelve reference stations described above are used to take the alignment measurements. For location of these stations, see Figure 2.

(a) The purpose of these measurements is to determine the horizontal displacements of the machine floor relative to an optical line of sight. A Wild T-2 theodolite and targets with optical plumbs were used to measure small horizontal displacements (offsets) of the alignment stations from an optical line of sight. The line of sight is referenced to the stations at each end of the turbine table.

(b) The following procedure is used to take the measurements. The T-2 is placed centrally by optical plumbing on the alignment target cemented on the designated area of the reference station (see Figure 1, detail 'B') at one end of the unit. A fixed target is similarly placed over the alignment target on the reference station at the other end of the unit, establishing an optical line of sight. Once the instruments are plumbed over their reference stations they are not moved during the series of measurements. A movable target, which carried a modified precision vernier caliper scale (for adjusting the target at right angles to the line of sight) is similarly set up over each of the four "in between" stations and their offset measurements are taken. With extreme care in setting the targets and adjusting the plane of the scale at right angles to the line of sight, the horizontal displacements (offset), to the left or right of the line of sight, can be measured to an estimated accuracy of +/- 0.25 mm. Repeatability error due to the setting up of the instruments relative to the reference target introduces an estimated additional +/- 0.25 mm in to the reading accuracy of each measurement. Any heat or vibration produced when the unit is running decreases this accuracy. The movable target vernier is calibrated in inches. These alignment readings are taken on both sides of the turbine table. It was not possible to obtain initial datum readings for Unit 2 due to obstructions on the turbine table. (Initial datum readings are presented in Table III.)

TEMPERATURE MONITORING (UNIT 2)

Thirty thermocouples were embedded in the concrete of the turbine table of Unit 2. The majority of the thermocouples are in the HP end of the unit.

The thermocouples are located at three different elevations in the turbine table. The thermocouples are designated by a letter, followed by a number from 1 to 30. The letter indicates the elevation of the thermocouple: (T) thermocouple is located 210 mm below the top of the table, (M) thermocouple is located in middle of table approximately at elevation 112.50 m, (B) thermocouple is located approximately 280 mm above the bottom of the table (elevation varies with location on table).

The thermocouples are terminated in seven readout boxes located in the bottom of the turbine table between support columns C-1A and C-2A at elevation 110.35 m.

Monitoring of these thermocouples during the running condition of the generator unit will identify any areas of excessive heat build up in the concrete structure. An added benefit of these thermocouples was found during the pouring of the turbine table. The heat of hydration of the concrete was monitored during curing and the concrete forms were able to be stripped earlier than expected. The locations of these thermocouples are shown in Figure 3. The numbering system for the thermocouples is shown in Table VI.

EXTENSOMETER STATIONS

Twelve extensometer stations were located between the top surface of each pier column and the underside of the machine support table. Stations G-1A to G-6A are located on the south side of the foundation and stations G-1 to G-6 are located on the north side of the foundation. For location of these stations, refer to Figure 4.

(a) The purpose of these stations is to monitor the displacement or gap between the "fixed" top of the pier columns and the "movable" underside of the machine support table,ie, to monitor the effect of different loading conditions on the table and the effects of spring adjustment. These measuring stations consist of a set of vertically opposed reference pins permanently fixed in an accessible location for reading as shown in Figure 1, detail 'A'.

The reference pins installed in the top of the pier columns are fastened in place by means of a 1/2 - 13 NC drill anchor (same thread size as the pin) and tack welded after the correct position has been established. The upper reference pins are threaded and tacked to a 2 inch square steel plate 1/2" thick, which is tack welded in place to the steel plate on the underside of the machine support table. When the pins are not in use, the parallel reference surfaces are protected by a 32 mm diameter x 44.5 mm long brass cap.

(b) Measurements are made with an inside micrometer extensometer (Mitutoyo No 137-104) coupled with extension rods. The instrument assembly is designed to give repeatable readings of differential movement with an accuracy of 0.05 mm. Results of the initial datum readings are shown in Table IV (A and B).

PLUMB LINE MEASUREMENTS

Four plumb line locations were selected on the machine table support columns at the four extreme corners of the foundation. The suspension points for these plumb lines are on the underside of the machine support table at elevation 110.00 m. The location of these plumb lines are shown in Figure 5.

(a) The purpose of the plumb line installation is to measure movement of the machine support table in two horizontal directions with respect to the base of the pier columns, and to augment the data provided by the alignment stations. Each installation consists of an arrangement of the following assemblies: (a) a suspension assembly fastened to the support table at elevation 110.00 m to which the plumb line wire is anchored, (b) an assembly of 4 inch conduit approximately 9 m long fastened to the support columns which protects the plumb line wire, (c) a micrometer reading table assembly and bracket which is fastened to the support column at 100.8 m elevation, (d) a cylindrical dashpot filled with SAE-90 oil, located directly below the reading head at elevation 100.00 m which provides damping for the plumb line weight, and (e) a removable sheet metal cover assembly located at elevation 100.0 m to provide protection for the reading table and dashpot when

not in use. The plumb line installation and assembly details are shown in Figure 6.

(b) By measuring the apparent movement of the plumb lines, the horizontal movements of the machine support table (115.0 m elevation) of the support columns are determined in the form of longitudinal and transverse deflections. Measurements are made by alternately placing the micrometer head (Mitutoyo Depth Micrometer Model 229-115) against the reference pins, in all four directions, provided in the measuring block. This method of measuring the wire from opposite directions allows instant detection of any gross errors in reading the micrometer (the total reading, the sum of the readings in opposite directions should always be the same). To take the readings, a flashlight is used to "backlight" the wire and the micrometer spindle is advanced until no light can be seen between the spindle and the invar wire. This method shows good repeatability of readings. Movements of the plumb lines are determined in terms of the differences between successive readings. It is estimated that the plumb line measurements can be made to an accuracy of +/- 0.125 mm. Initial datum readings for the four plumb lines are listed in Table V (A and B).

INVAR ROD MEASUREMENTS (UNIT 2)

(a) An invar rod extensometer is hung from the top of the machine floor of Unit 2 (elevation 115.0 m) to elevation 100.58 m, just above the ground floor. It is situated in the southwest corner of the machine floor at the HP end of the unit. When this extensometer is referred to a permanent rock anchored benchmark (DRBM), information relating to the total settlement of the top of the machine foundation can be readily obtained.

The extensometer consists of a 20 mm diameter by 14.39 m long invar rod suspended from a fixed bracket at elevation 115.0 m. The details of the suspending bracket are shown in Figure 7, detail 'A'. The 14.39 m length of the extensometer is composed of three lengths of invar rod joined together with special joints. The invar rod joint details are shown in Figure 7, detail 'B'. A 4 mm diameter stainless steel ball is soldered to the lower end of the rod. The measuring bracket for supporting the standard micrometer head (Starrett No 263RL) is installed and positioned to provide a gap of about 20 mm between the steel ball and the end of the micrometer spindle. These details can be seen in Figure 8. Differences of successive measurements of this gap provide a history of the top of the turbine table relative to the base of the support columns. The elevation of this bracket is also compared to the deep anchored rock benchmark. The measurement procedure is as follows:

1) Insert the micrometer head (Starrett No 263RL) in the bottom of the measuring bracket in the machined seat. Take three readings of the gap 'x' (see Figure 8).

2) The elevation of the measuring bracket is taken (using the attached reference pin, the same as the column reference pins) relative to the permanent benchmark (DRBM), using precise leveling procedures.

3) The elevation of the top of the invar rod on the machine floor, elevation 115.0 m, is related to the nearest upper settlement/alignment station. On Unit 2 this is station #T-1A. The initial measurements for the extensometer are tabulated in Table VII..pa

REFERENCE BENCHMARK (UNIT 2)

A deep rock-anchored benchmark (DRBM) was installed from elevation 100.0 m near the invar rod extensometer in Unit 2. The benchmark is situated near column C-1A at chainage 10,056.200N m and 10,064.000Em. The benchmark consists of a 20 mm diameter steel rod anchored in the bedrock at a depth of 12.2 m below the finished floor. This rod is encased in 76 mm black iron pipe to prevent interference from overburden movement. The rod is centred in the casing with rubber "spacers". The casing is filled with heavy grade oil to within 15 cm of the top. A stainless steel spherical seat is attached to the top of the rod to provide a suitable surface for the leveling rod during measurements. A flush mounted cap, flush with the finished floor elevation 100.0 m, provides protection for thebenchmark. Details of the rock-anchored benchmark can be seen in Figure 9.

3.0 SUMMARY

The instrumentation program for the turbo-generator foundations has been tailored to obtain the following measurements:

(a) vertical and horizontal movement in the machine table

(b) vertical movement of the support columns at the ground floor level

(c) distortion of the top of the machine support table relative to the support columns

(d) a temperature profile of the machine support table concrete in the running condition (Unit 2 only).

The available initial datum readings for Units 1 and 2 have been taken and are recorded in this report. An addendum will report any subsequent readings when they are taken.

Approved by:

T.W. Klym
Manager
Civil Research Department

Prepared by:

D.S. Fraser
Technician
Soil Sciences Section

Reviewed by:

C.B.H. Cragg
Senior Engineer
Soil Sciences Section

DSF:LM

TABLE I(A)

Differential Vertical Elevations
Darlington GS Unit 2 Elevation 101.0 m
(Column Stations)

Datum Readings

Date: August 28/85

Elevation (mm) relative to Station C-1A
Closure Error (0.51 mm) corrected

Station No	C-1	C-1A	C-2	C-2A	C-3	C-3A	C-4	C-4A	C-5	C-5A	C-6	C-6A
	+2.63	0.00	+0.59	+1.54	+1.49	+1.20	+4.57	-1.28	+4.84	+1.29	+4.38	+5.75

+ve - Station is higher than datum station
-ve - Station is lower than datum station

TABLE II(A)

Differential Vertical Elevations
Darlington GS Unit 2 Elevation 115.0 m
(Machine Table Stations)

Datum Readings

Date: Aug 20/85

Elevation (mm) relative to Station T-1A
Closure Error (0.15 mm)

Station No	T-1	T-1A	T-2	T-2A	T-3	T-3A	T-4	T-4A	T-5	T-5A	T-6	T-6A
	-4.80	0.00	-7.28	-7.60	-0.98	-7.80	-5.94	-7.63	+5.64	-9.59	+0.66	+4.51

+ve - Station is higher than datum station
-ve - Station is lower than datum station

TABLE I (B)

Differential Vertical Elevations
Darlington GS Unit 1 Elevation 101.0 m
(Column Stations)

Datum Readings

Date: Feb 13/86

Elevation (mm) relative to Station C-1A
Closure error (0.15) mm corrected

Station No	C-1	C-1A	C-2	C-2A	C-3	C-3A	C-4	C-4A	C-5	C-5A	C-6	C-6A
	9.36	0.00	1.67	12.08	-3.72	-1.16	-1.96	0.61	-1.90	3.11	47.93	-11.80

+ve - Station is higher than datum station
-ve - Station is lower than datum station

TABLE II(B)

Differential Vertical Elevations
Darlington GS Unit 1 Elevation 115.0 m
(Machine Table Stations)

Datum Readings

Date: February 11/86

Elevation (mm) relative to station T-1A
Closure Error (0.20 mm) corrected

Station No	T-1	T-1A	T-2	T-2A	T-3	T-3A	T-4	T-4A	T-5	T-5A	T-6	T-6A
	8.62	0.00	-5.42	10.06	1.35	6.42	0.30	-1.63	27.76	5.76	3.48	-2.12

+ve - Station is higher than datum station
-ve - Station is lower than datum station

TABLE III

Differential Horizontal Movements
Turbo-Generator Foundation
Darlington GS
Unit 1

Datum Readings

Date: February 13/86

Station No	Side	Average Reading
T-1	North	Theodolite Station
T-2		83.85 mm
T-3		89.03 mm
T-4		86.03 mm
T-5		89.76 mm
T-6		Target - 83.77 mm
T-1A	South	Theodolite Station
T-2A		83.82 mm
T-3A		85.09 mm
T-4A		83.08 mm
T-5A		91.01 mm
T-6A		Target - 84.33

TABLE IV(A)

Darlington GS Unit 2
Extensometer Datum Readings

Date: August 21/85

Gap Station No	Mic Reading (mm)	Extension Rods (mm)	Measured Length (mm)
G-1	4.85	13+25+50+50+100+200+300	742.85
G-1A	4.06	13+25+50+50+100+200+300	742.06
G-2	4.01	13+25+50+50+150+200+300	792.01
G-2A	2.59	13+25+50+50+150+200+300	790.59
G-3	6.21	25+50+50+100+150+200+300	881.21
G-3A	5.03	25+50+50+100+150+200+300	880.03
G-4	6.77	25+50+50+100+150+200+300	881.77
G-4A	1.63	13+25+50+50+100+150+200+300	889.63
G-5	7.80	25+50+50+100+150+150+200+300	882.80
G-5A	2.14	13+25+50+50+100+150+200+300	890.14
G-6	10.84	25+50+50+100+150+200+300	885.84
G-6A	11.44	25+50+50+100+150+200+300	886.44

TABLE IV(8)

Darlington GS Unit 1
Extensometer Datum Readings

Date: February 14/86

Gap Station No	Mic Reading (mm)	Extensometer Rods (mm)	Measured Length (mm)
G-1	11.29	25+50+100+200+300	686.29 Aug 21/86
G-1A	6.41	25+50+100+200+300	681.41 Aug 21/86
G-2	12.37	13+25+50+50+150+200+300	800.37
G-2A	5.58	13+25+50+50+150+200+300	793.58
G-3	11.11	25+50+50+100+150+200+300	886.11
G-3A	9.15	25+50+100+50+250+200+300	884.15
G-4	1.81	13+25+50+100+50+150+200+300	889.81
G-4A	3.81	13+25+50+100+50+150+200+300	891.81
G-5	11.21	25+50+100+50+150+200+300	886.21
G-5A	1.20	25+50+100+50+150+200+300	876.20
G-6	2.05	13+25+50+100+50+150+200+300	890.05
G-6A	2.20	25+50+100+50+150+200+300	877.20

TABLE V(A)

Plumb Line Measurements
Darlington Unit No 2

Datum Readings Date: January 21/86

Measuring Station No	Micrometer Readings (mm) North	South	Total	East	West	Total
P-1 Average	38.40	40.34	78.74	38.22	40.63	78.85
P-1A Average	39.27	39.67	78.94	40.86	38.04	78.90
P-6 Average	39.61	obstruction	N/A	37.91	40.92	78.83
P-6A Average	obstruction	39.51	N/A	37.37	41.49	78.86

NOTE: Subsequent readings higher than datum will indicate a movement away from the quadrant being read

TABLE V(B)

Plumb Line Measurements
Darlington Unit No 1

Datum Reading August 21/86

Measuring Station No	Micrometer Readings (mm) North	South	Total	East	West	Total
P-1 Average	13.04	15.64	28.68	15.59	13.20	28.69
P-1A	13.91	14.98	28.89	15.59	13.14	28.73
P-6	14.56	obstructed		14.93	13.60	28.53
P-6A	obstructed	15.50		14.56	14.19	28.75

Note: Subsequent readings higher than datum will indicate a movement away from the quadrant being read

These readings were taken with the table partially loaded

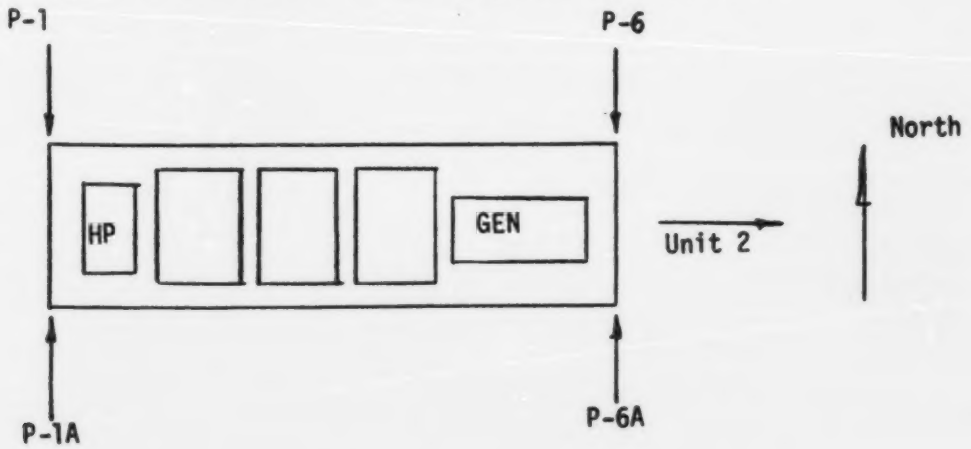


TABLE VI

Numbering System for Thermocouples
Located in Turbine Table Unit No 2

Outlet Box No	Switch Position in Box					
	1	2	3	4	5	6
1	T1	T2	M3	B4	B5	T15
2	B16	T23	B24	M27	T11	B13
3	T12	B14	M20	T19	B22	M21
4	T7	B10	M8	T6	B9	T17
5	B18	T25	B26			
6	T28	B29	T30	B31	M37	
7	T32	B33	M36	T34	B35	

TABLE VII

Invar Rod Extensometer
Darlington GS Unit No 2

Date: August 28, 1985

Deep rock benchmark elevation	= 99.955 M
Difference in elevation between DRBM and survey pin on invar rod bracket	= 67.969 CM
Difference in elevation between DRBM and survey pin on column (STA.CIA)	= 106.838 CM
Micrometer reading gap 'x'	= 12.86 MM

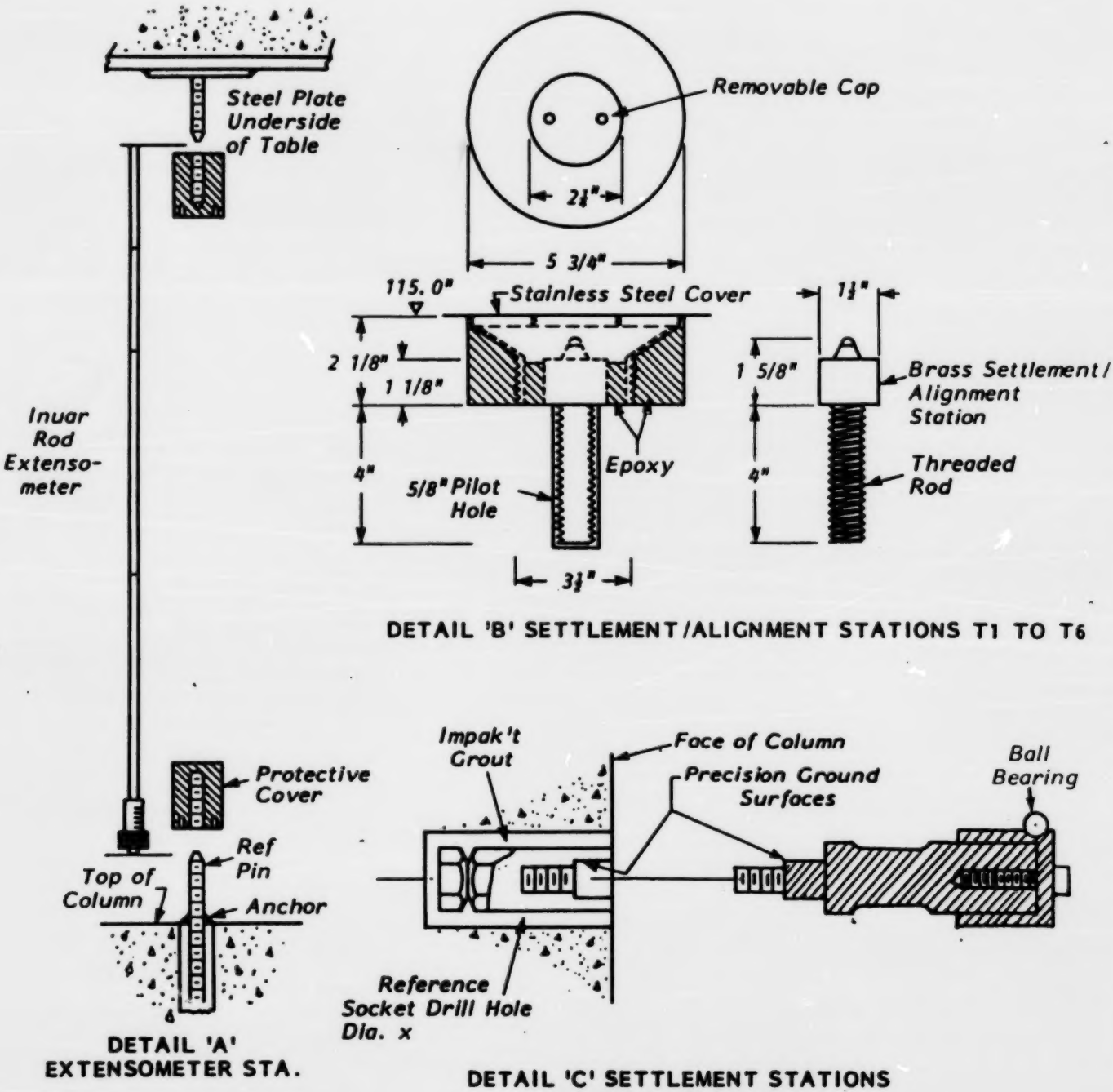
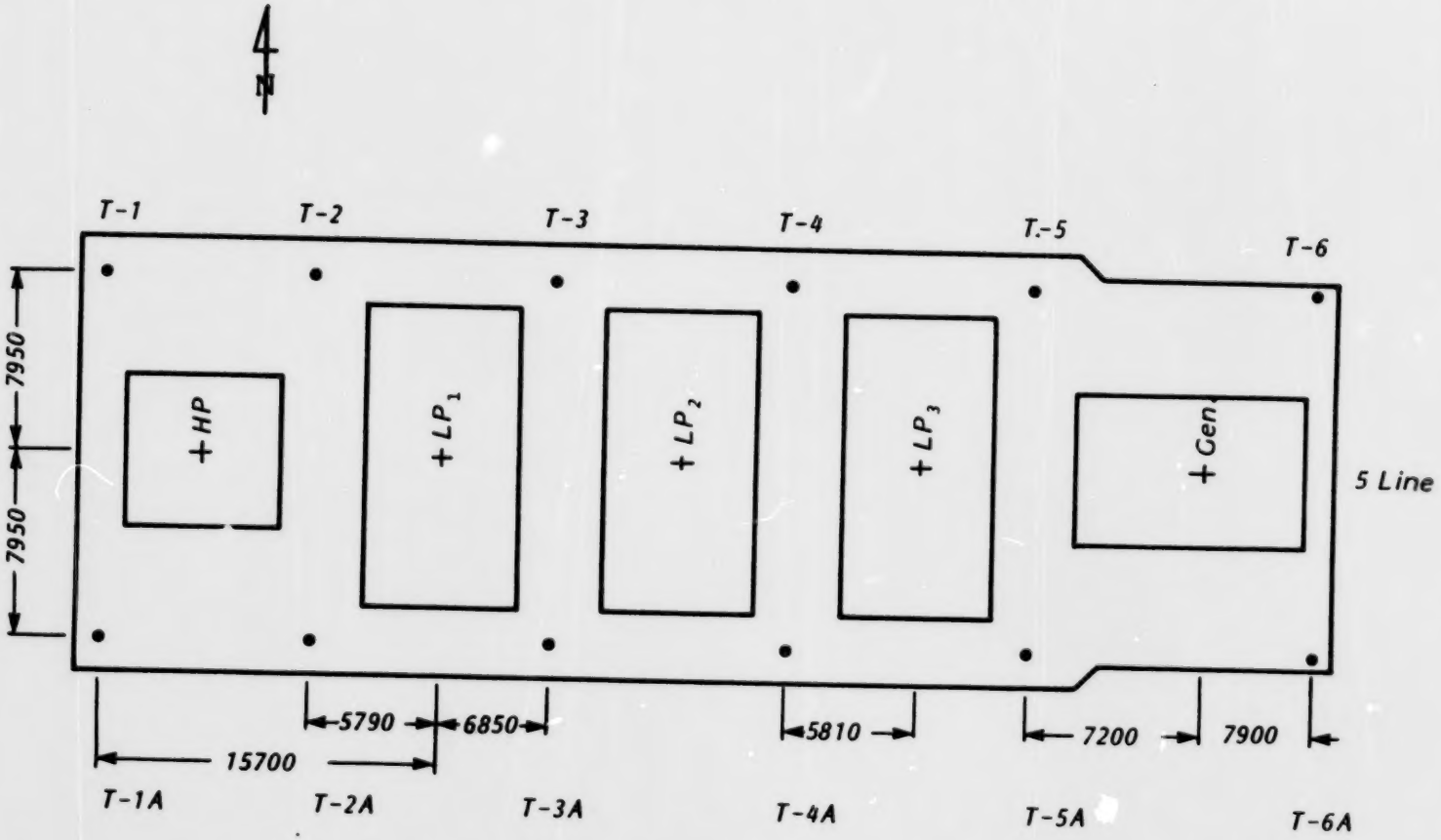


FIGURE 1

DETAILS OF COLUMN TABLE AND GAP STATIONS FOR DARLINGTON NGS TURBOGENERATOR

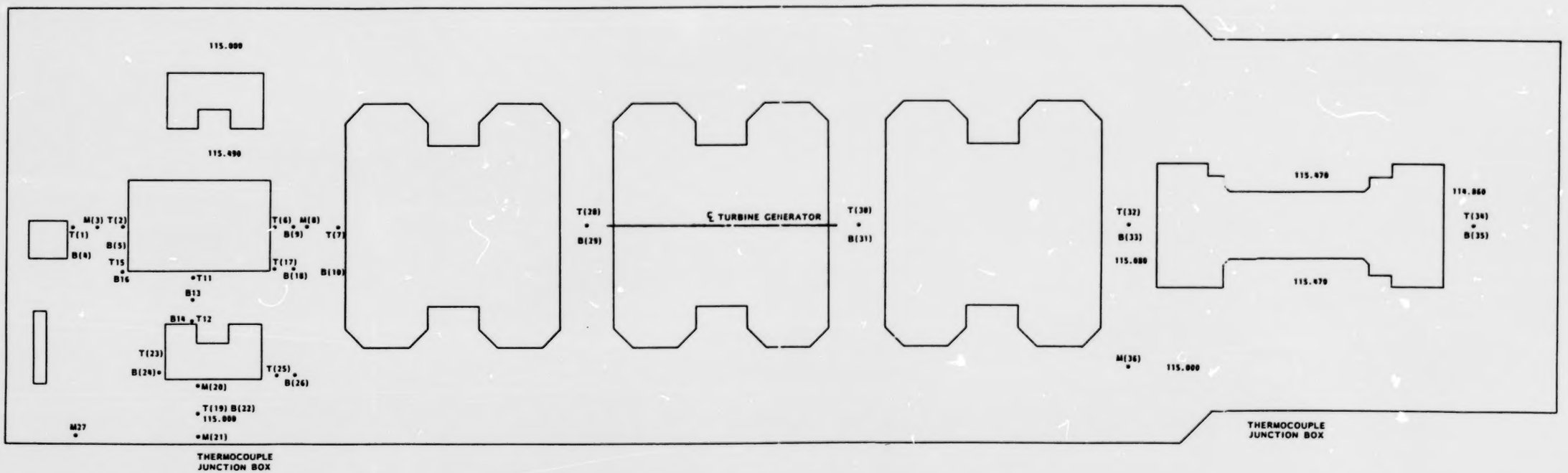


• Elevation/Alignment Stations 115 Elev.
(Distances shown are in mm)

FIGURE 2

DARLINGTON GS UNITS 1 AND 2
ELEVATION/ALIGNMENT STATIONS - 115 ELEV

169075 RD



Thermocouples	Location	Elevation
T	210 mm below top of slab	114.8 m
M	middle of slab	112.5 m
B	280 mm above bottom of beams	110.3 m

FIGURE 3
THERMOCOUPLE LOCATIONS ON TURBINE TABLE UNIT NO. 2

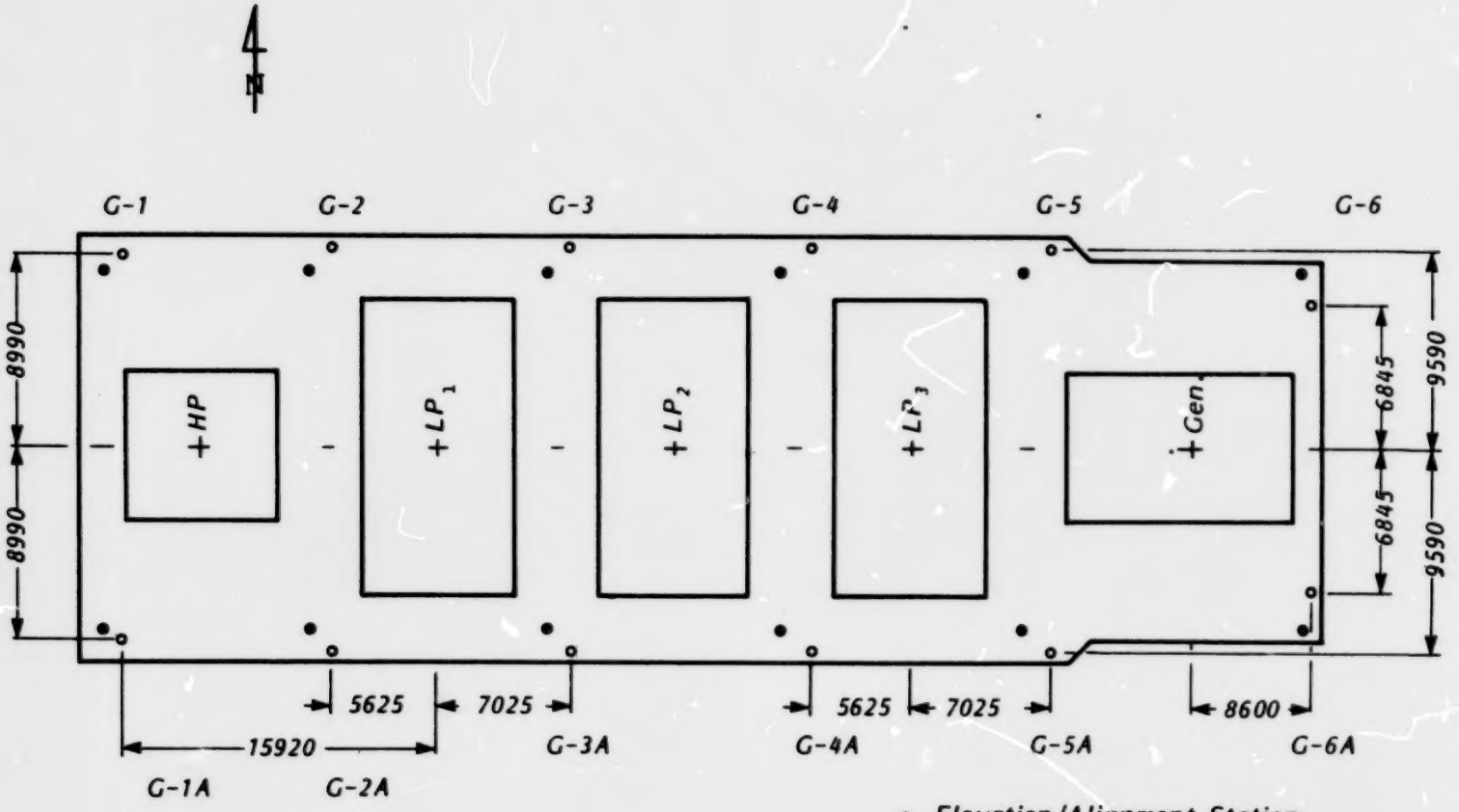


FIGURE 4
DARLINGTON GS UNITS 1 AND 2
SPRING SUPPORT GAP STATION LOCATIONS

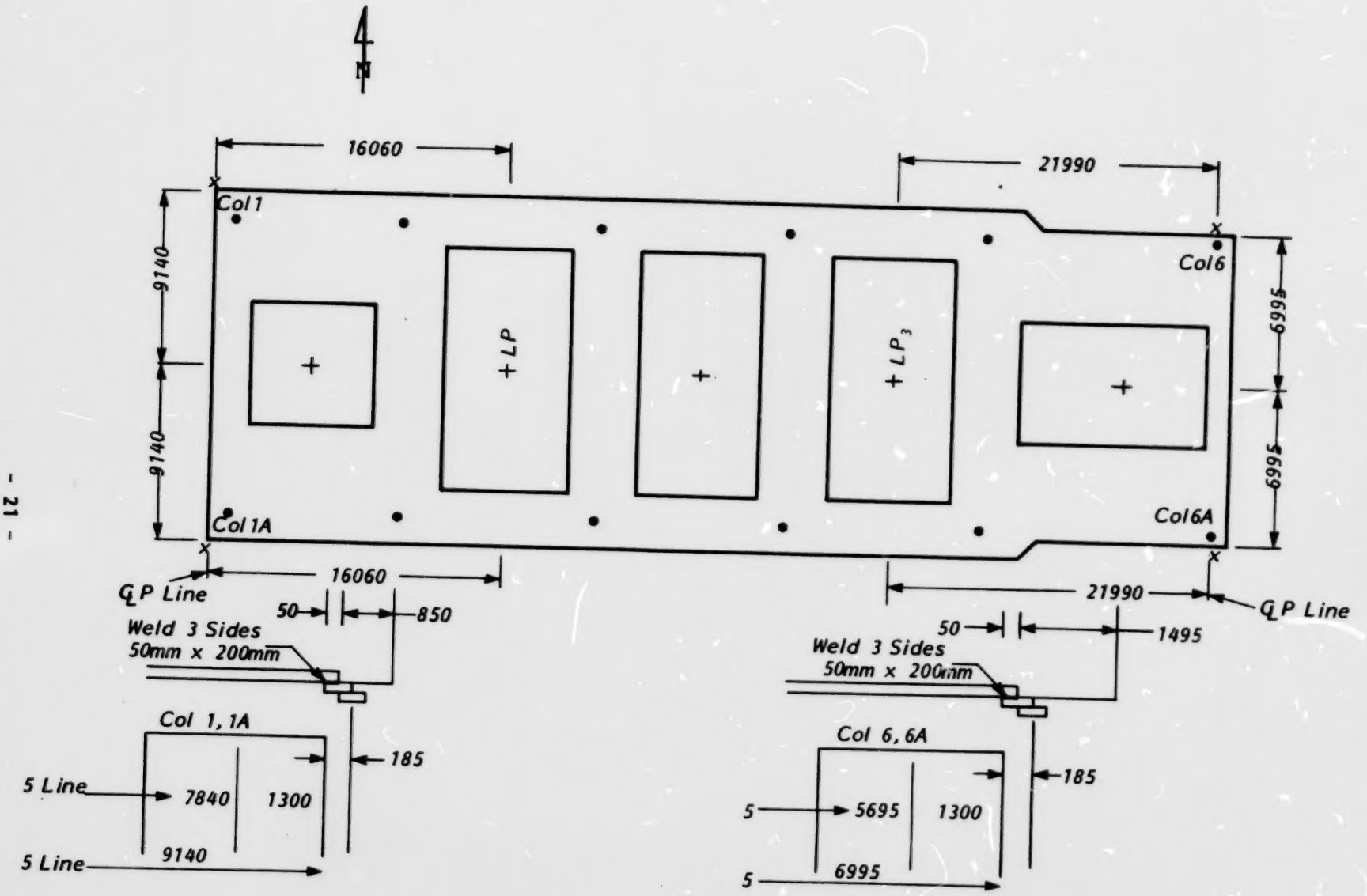
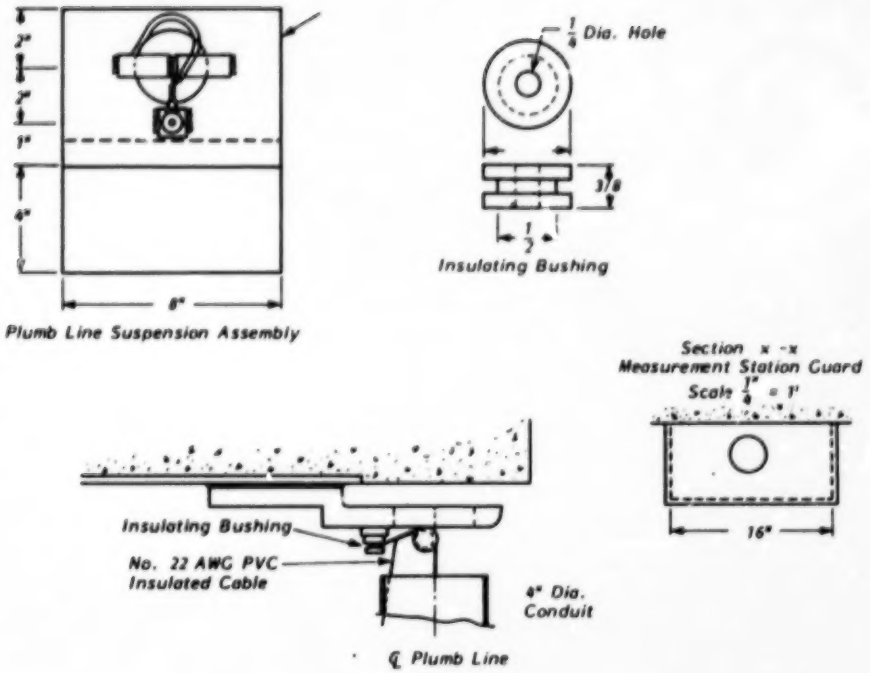


FIGURE 5
DARLINGTON GS UNITS1 AND 2
PLUMB LINE LOCATIONS 110 ELEV



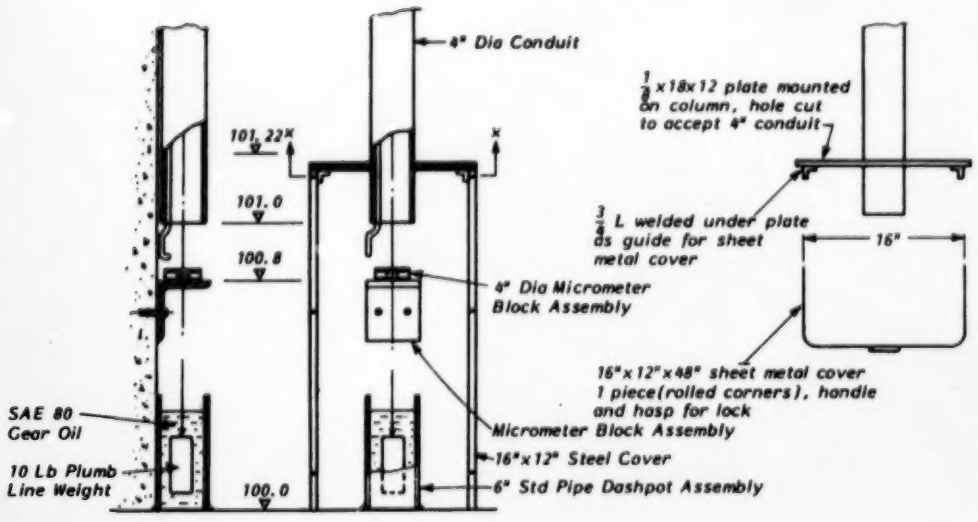
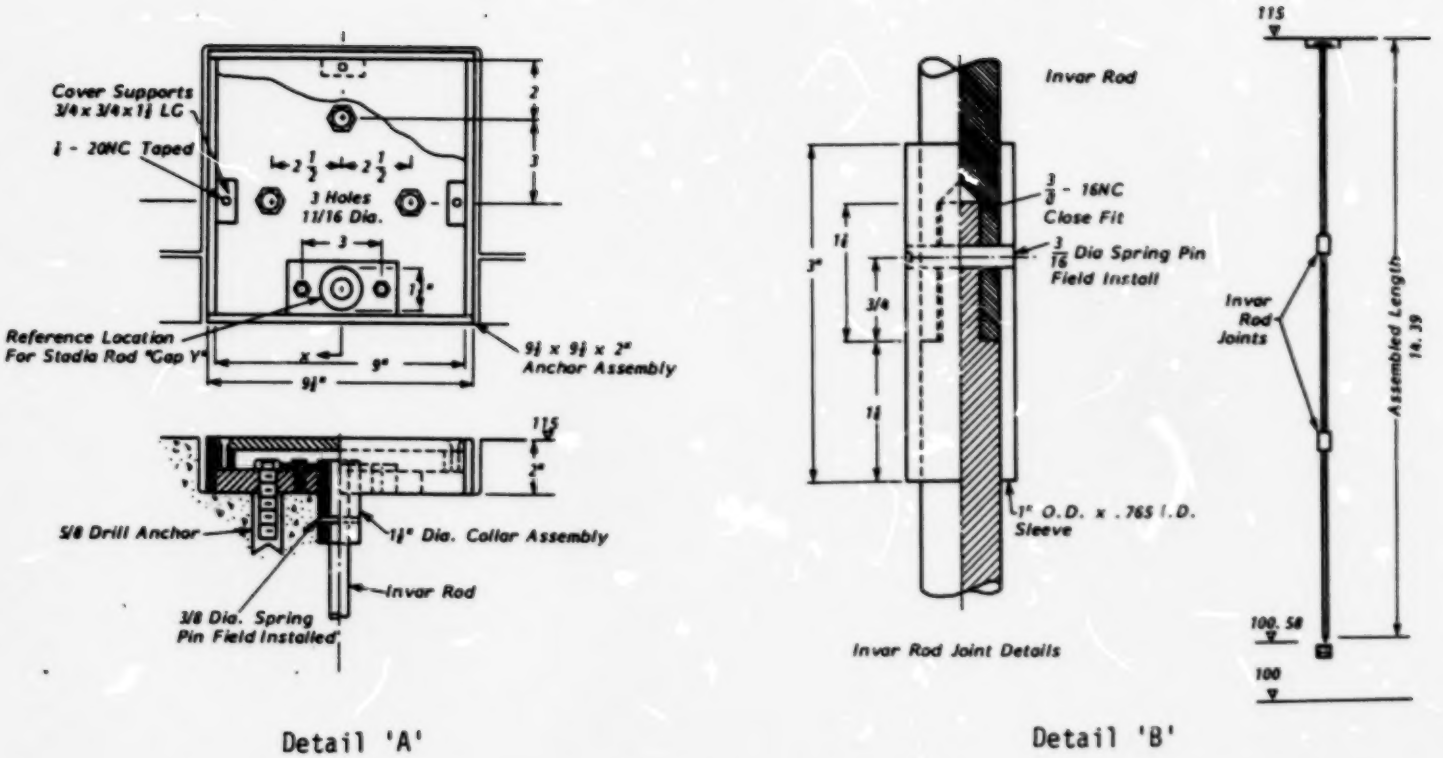


FIGURE 6

DETAILS OF PLUMB LINE STATIONS FOR DARLINGTON NGS TURBOGENERATOR

200415 RD



Detail 'A'

Detail 'B'

FIGURE 7

DETAILS OF INVAR EXTENSOMETER
DARLINGTON NGS TURBOGENERATOR

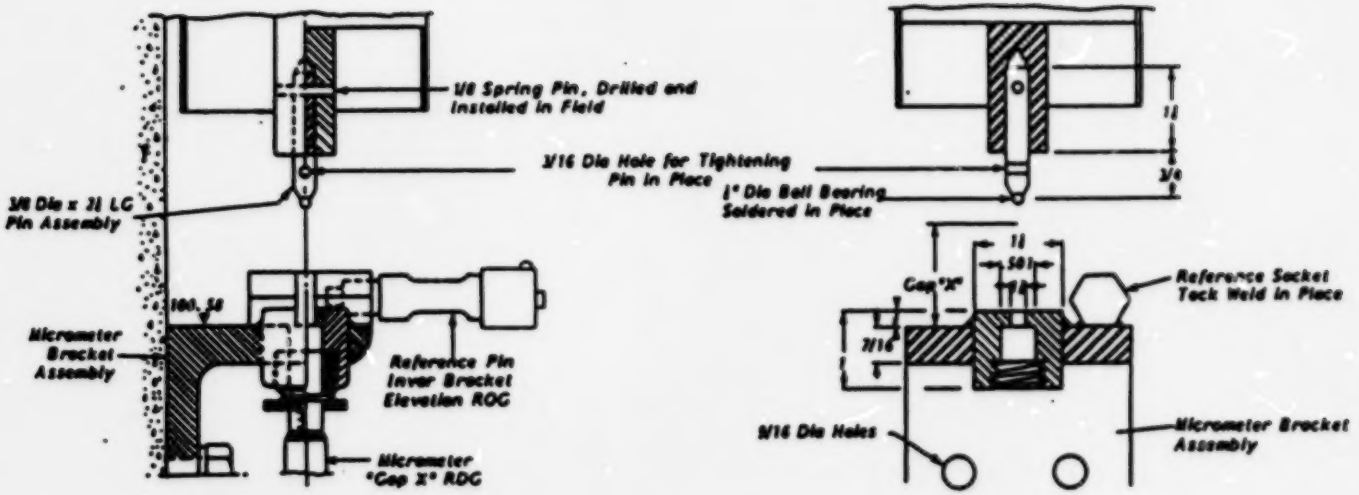

1/8 Spring Pin, Drilled and Installed in Field
3/16 Dia Hole for Tightening Pin in Place
1" Dia Ball Bearing Soldered in Place
1/8 Dia x 1½ LG Pin Assembly
Micrometer Bracket Assembly
Reference Pin Invar Bracket Elevation ROC
Micrometer "Cap X" ROC
Reference Socket Tack Weld in Place
3/16 Dia Holes
Micrometer Bracket Assembly

FIGURE 8

DETAILS OF INVAR EXTENSOMETER GAP STATION
AND SURVEY REFERENCE PIN

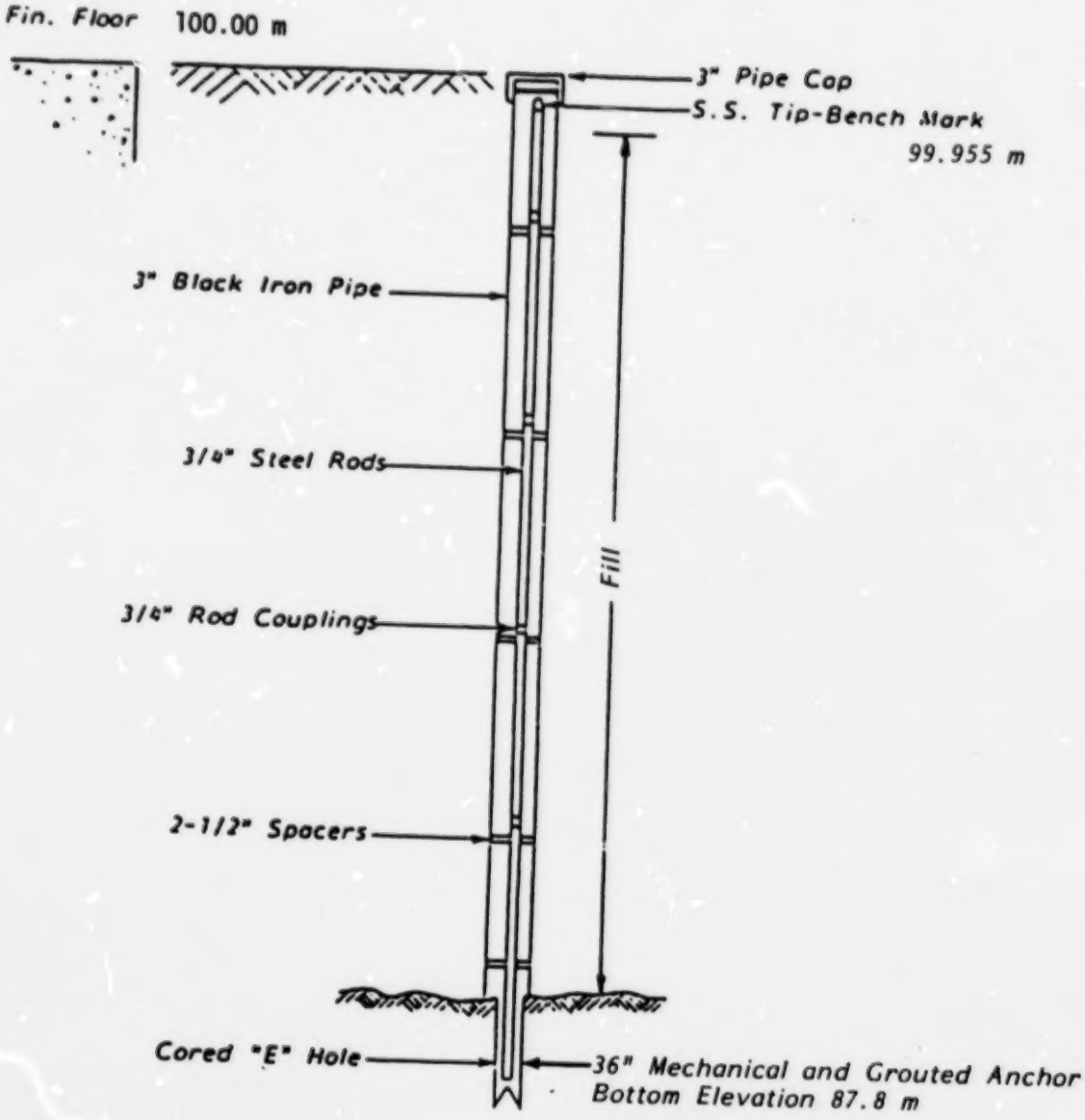


FIGURE 9
ROCK ANCHORED BENCH MARK PROFILE
DARLINGTON GS UNIT NO 2

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